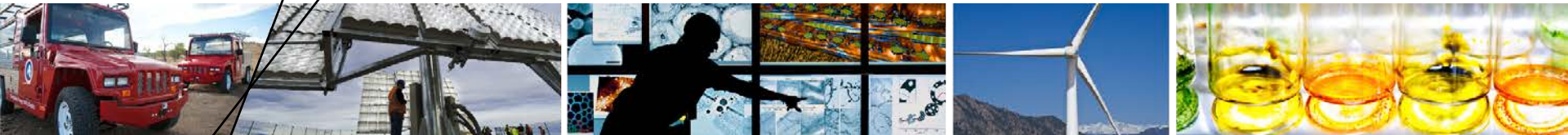


# Emergent Considerations for Advanced Inverter Deployment



**DG Interconnection  
Collaborative (DGIC)  
April 28, 2016**

**Emerson Reiter  
Project Lead  
National Renewable Energy Lab (NREL)**

**Ryan Edge  
Research Analyst  
Smart Electric Power Alliance (SEPA)**

**John Berdner  
Director of Global Regulatory Compliance  
Enphase Energy**

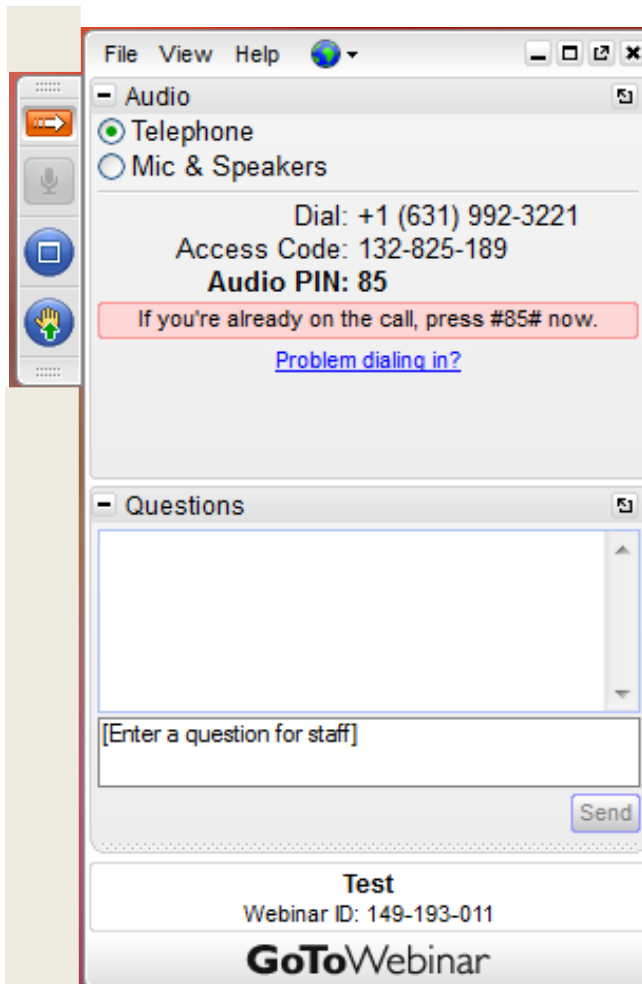
# Purpose of Today's Meeting

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- Learn how advanced or “smart” inverters can provide a technical solution to grid management challenges caused by increasing penetration of distributed PV generation.
- DGIC activities planned for 2016
  - At least two more webinars to come
    - Including lessons learned from NREL's utility technical assistance program



# Logistics



Participants are joined in listen-only mode.

← Use the Q&A panel to ask questions during the webinar.

← To ask a question: Type your question in the Q&A gotowebinar toolbar.

We will have a few minutes of Q&A between each presentation and group discussion at the very end.

The webinar is being recorded and will be posted on the DGIC site:  
[http://www.nrel.gov/tech\\_deployment/dgic.html](http://www.nrel.gov/tech_deployment/dgic.html)

# Agenda ( 1 ½ hour)

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5 *mins.* Overview of DGIC (Kristen Ardani - NREL)

55 *mins.* Informational Webinar:

- “Emergent Considerations for Advanced Inverter Deployment”

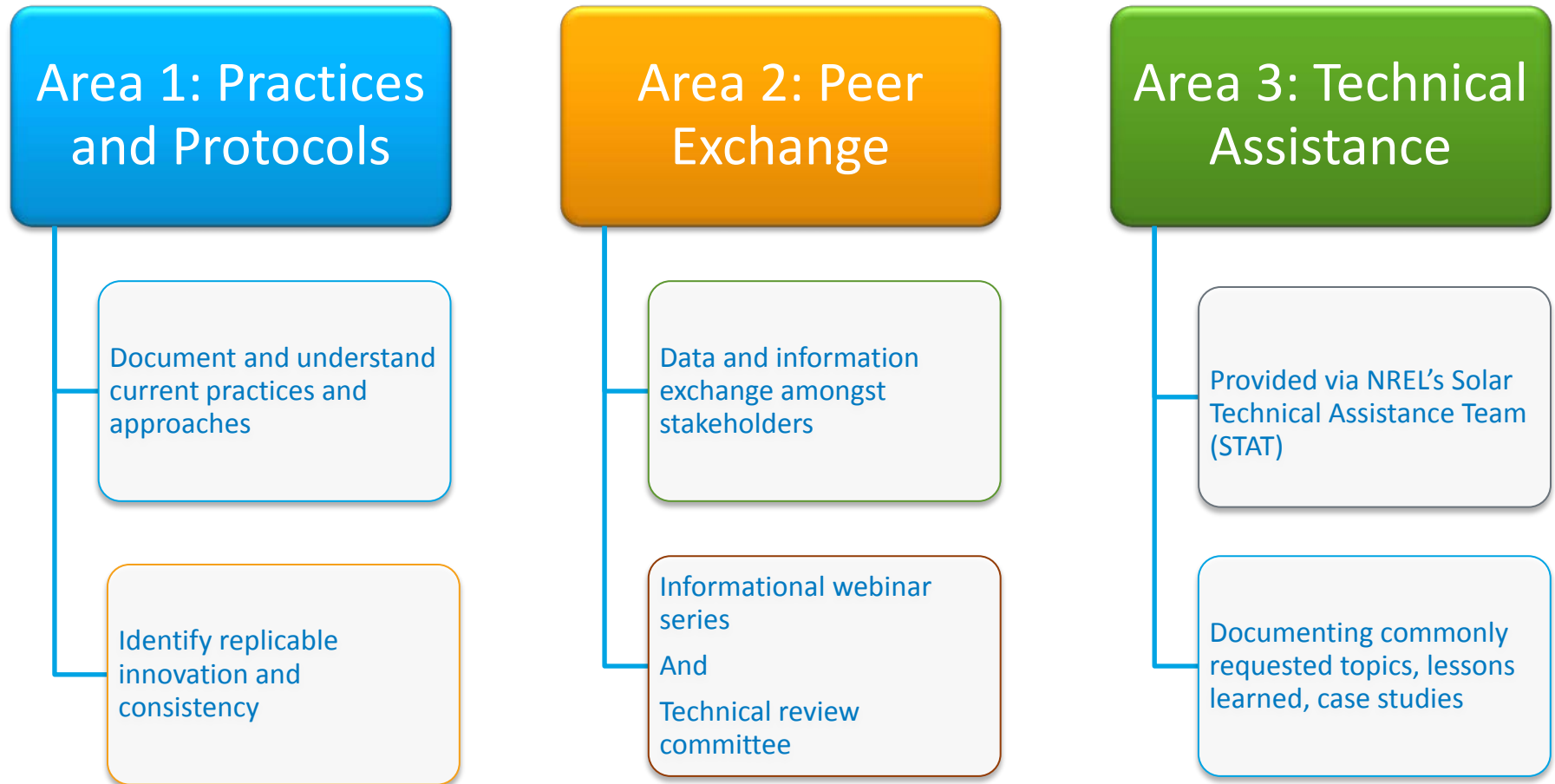
30 *mins.* Q&A/discussion

# DGIC Background and Context

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- Supported by U.S. DOE SunShot Initiative
- Formed following stakeholder workshop in October 2013
- Focused on informational exchange and innovation related to distributed PV interconnection processes and practices

# DGIC Framework and Activities



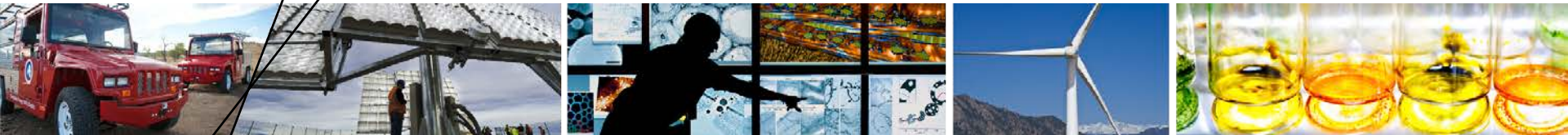
# DGIC and Technical Assistance Resources

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- **Participate in the Collaborative and shape the discussion by signing up through the DGIC web page, below:**

**[http://www.nrel.gov/tech\\_deployment/dgic.html](http://www.nrel.gov/tech_deployment/dgic.html)**

# Emergent Considerations for Advanced Inverter Deployment



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# Speakers



**Emerson Reiter**  
**Project Lead**  
**National Renewable Energy Lab (NREL)**



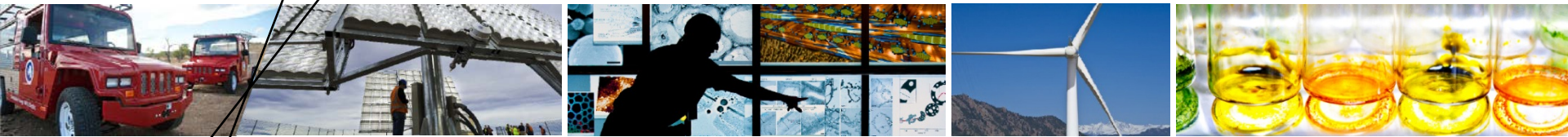
**Ryan Edge**  
**Research Analyst**  
**Smart Electric Power Alliance**  
**(SEPA)**



**John Berdner**  
**Director of Global**  
**Regulatory**  
**Compliance**  
**Enphase Energy**



**Kristen Ardani**  
**Solar Analyst (DGIC Moderator)**  
**NREL**



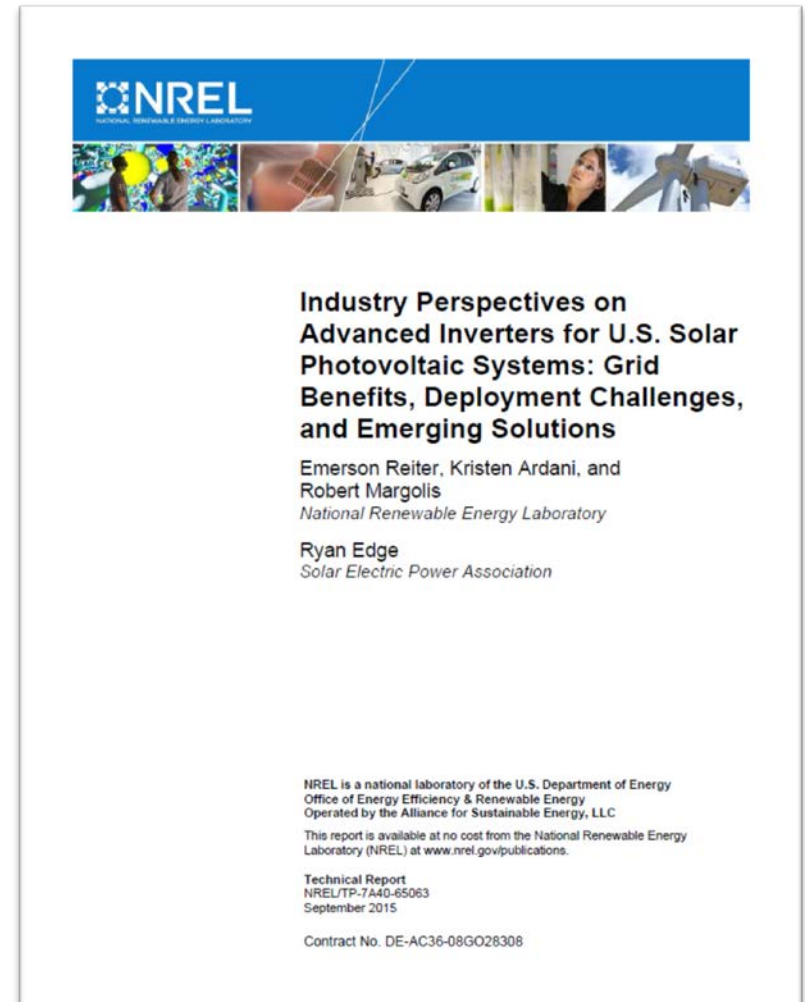
# **Industry Perspectives on Advanced Inverters for U.S. Solar Photovoltaic Systems**

**Emerson Reiter**

**April 28, 2016**

# Agenda

- Motivation
- What Makes an Inverter “Advanced” or “Smart?”
- Key Barriers to Adoption
- Comparison of AZ Experiences
- Conclusions



# Motivation – State of Solar PV Deployment

gtm: Search Greentech Media

GE's Current Buys Networked Lighting Firm Daintree Networks for \$77M

The US Solar Market Is Now 1 Million Installations Strong


The Perils of PV Price Prediction

MARKETS & POLICY

## The US Solar Market Is Now 1 Million Installations Strong

Customers weigh in on what it's like to be one of a million.

by Julia Pyper  
April 21, 2016

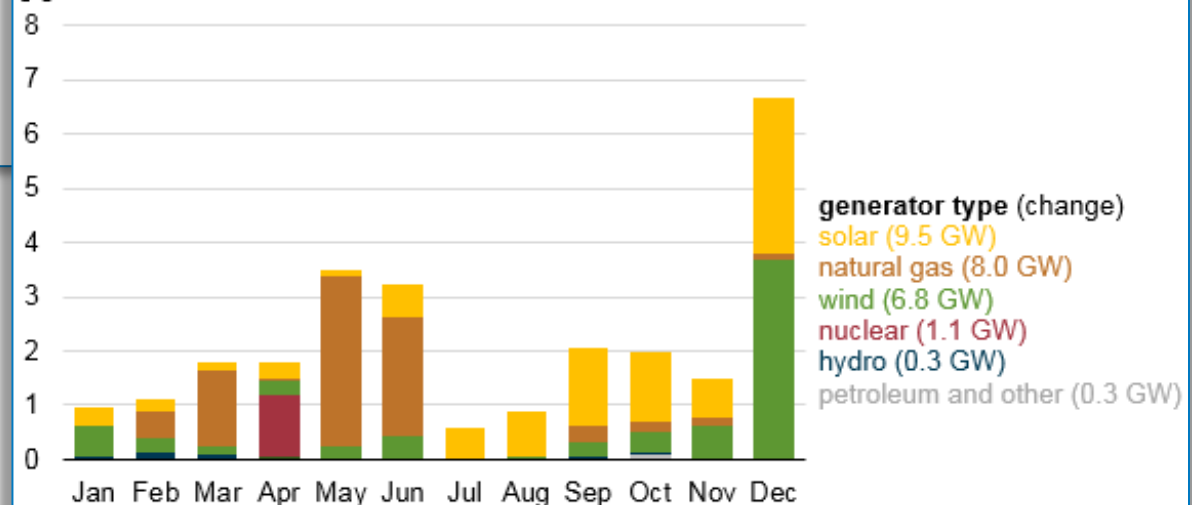


Sometime around the end of February, the millionth solar installation came on-line in the United States -- a milestone that says as much about where the solar industry is going as it does about how far the industry has come.

"It took us 40 years to get to 1 million installations, and it will take us only two years to get to 2 million," said Dan Whitten, vice president of communications at the Solar Energy Industries Association (SEIA). "This is a time to mark when the solar industry started to accelerate at warp speed."

At the end of 2015, the U.S. solar market hit a total capacity of 27 gigawatts. That

Scheduled electric generating capacity additions in 2016  
gigawatts



# Motivation - Utility Actions

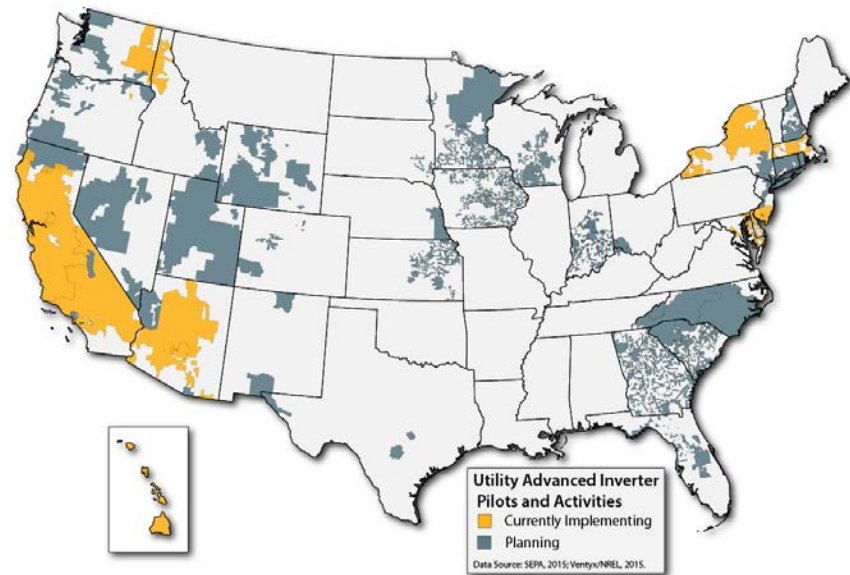
## Smart Electric Power Alliance (SEPA) Q1 2015 Survey

122 utility responses

58 (48%) reported activity related to advanced inverters

15 (12%) currently implementing a project or program involving advanced inverters

43 (35%) planning, considering or researching deployment of advanced inverters



# What is a “Smart” Inverter - Functions

Multiple efforts have been made to standardized function set for smart inverters

Some key capabilities include:

Function	Description
Connect/disconnect	Electrically connects to or disconnects from the grid
Maximum generation limit	Constrains real power output
Volt-VAR function	Adjusts reactive power output based on service voltage
Volt-Watt function	Adjusts real power output based on service voltage
Frequency-Watt function	Adjusts real power output based on service frequency
Low/high frequency ride-through	Defines frequency range for which inverter remains on-line
Low/high voltage ride-through	Defines voltage range for which inverter remains on-line
Event/history logging	Log and report standardized set of events
Status reporting	Report current device status

**For More:**

EPRI, Common Functions for Smart Inverters, Version 3, Report # 3002002233

<http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002002233>

Distributed Energy Management (DER): *Advanced Power System Management Functions and Information Exchanges for Inverter-based DER Devices, Modelled in IEC 61850-90-7*

[http://xanthus-consulting.com/Publications/documents/Advanced\\_Functions\\_for\\_DER\\_Inverters\\_Modelled\\_in\\_IEC\\_61850-90-7.pdf](http://xanthus-consulting.com/Publications/documents/Advanced_Functions_for_DER_Inverters_Modelled_in_IEC_61850-90-7.pdf)

# What is a “Smart” Inverter - Benefits

---

- **Increased grid stability**
  - Local – voltage control from volt-VAR and volt-Watt functions
  - System – greater resiliency during voltage or frequency deviations
- **Increased visibility into distribution system conditions via data collection**
- **Potential to defer investments in other distribution system hardware**

# Key Barriers - Summary

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- **On-going, multi-party engagement**
- **Technology ahead of governing standards**
- **Burden of establishing communications infrastructure**
- **Lack of compensation for services**



# Key Barriers – Technical Standards

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## Key Standards for Advanced Inverters

- **UL 1741**

- Developed by Underwriter's Laboratory (UL)
- Primarily an *equipment safety* standard
- Sets design requirements and testing procedures

- **IEEE 1547**

- Developed by Institute of Electrical and Electronics Engineers (IEEE)
- Primarily an *interconnection performance* standard
- Governs how inverters affect electrical conditions at the point of common coupling (PCC) with the grid

# Key Barriers – Technical Standards

## Standards acted as a barrier because other regulations rely on these measures

### Equipment Safety

**UL 1741** does not have a testing procedure for advanced inverters



Without a developed testing program under UL 1741, advanced inverters cannot achieve **UL listing**



Installations using advanced inverters which are not UL-listed cannot comply with the **National Electrical Code**



Installations which do not comply with the National Electrical Code will violate **state or local building codes**

### Interconnection Performance

**IEEE 1547-2003** does not allow inverters to perform "advanced" functions beyond those in IEEE 1547a-2014



In most states, an inverter which violates IEEE 1547-2003 does not meet **state interconnection standards**



Inverter deployments which do not meet state standards will not pass **utility interconnection processes**

# Key Barriers - Communications

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## **Communications bring challenges and benefits**

### Challenges

- Many layers of physical and software infrastructure
- Standardization to maximize value requires coordination across many parties

### Benefits

- Enables certain high-value functions
  - E.g. real power curtailment
- Supports more frequent updates to otherwise-autonomous functions
- Increases visibility for distribution management

# Key Barriers - Communications

Communications Level		Inverter Functions	Proceedings and Standards	
Autonomous	– No communications architecture needed – Behavior controlled by operating parameters – Parameters defined at system commissioning – Parameters can be adjusted, behavior activated or deactivated at later date via remote or on-site changes	Low- / High-voltage ride-through	SIWG Phase 1	IEEE 1547a-2014
		Low- / High-frequency ride-through		
		Volt-var control		
		Anti-islanding		
		Ramp-rate controls		
		Provide reactive power (via fixed power factor)		
		Reconnect via “soft-start”		
		Frequency-watt	SIWG Phase 3	
		Voltage-watt		
		Dynamic current support		
		Smooth frequency deviations		
Non-Autonomous	– Communications and control infrastructure required – Direct control of inverter behavior – Control from remote operator commands or feedback, based on conditions at point of common coupling	Command DER to connect/disconnect	SIWG Phase 3	
		Limit real power		
		Set real power		
		Provide black-start capability		
		Respond to real power pricing signals		
		Participate in automatic generator control (AGC)		
		Provide spinning reserves or bid into market		
		Update static set points for autonomous functions (fixed power factor, volt-var curves, voltage ride-through, frequency ride-through)		

Adapted from: <http://www.pjm.com/~media/committees-groups/committees/pc/20140428-advance/20140428-item-04-sma-smart-inverter-grid-support-capabilities.ashx>

# Key Barriers - Compensation

---

- **Limited availability in wholesale markets**
- **Especially important when functions reduce real power output (energy delivered)**
  - Framework for valuing energy itself not settled
- **Larger distributed facilities may be required to deliver services without clear payment**
  - Operate off of unity power factor

# Case Study: AZ Utilities

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- **Advanced inverters a major component of rooftop solar programs**
- **Pilot program to gather data, assess true ability to address local issues, defer upgrades**
- **Targeted areas with high load and high (non-utility) PV penetration**
- **Communications choices tied to legacy infrastructure: APS (AMI) and TEP (AMR)**
- **Both view inverters in context of larger distribution management modernization**

# Conclusion

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- **Strong interest & need for advanced inverters**
- **Capabilities can speed integration of larger amounts of solar PV**
- **Standards obstacles are in the process of being addressed**
- **Communications issues being considered**
- **Compensation mechanisms will need to be created and standardized to drive greater deployment for distributed solar PV**

# Utility Roll-Out for Advanced Inverters

Ryan Edge  
Research Analyst



Smart Electric  
Power Alliance



## Collaboration between SEPA and EPRI

A look into the business  
strategies leading utilities  
are using to implement  
advanced inverter  
functionality

### Authors:

Ben York, EPRI

Nadav Enbar, EPRI

Ryan Edge, SEPA



# Utilities profiled

Pacific Gas & Electric

Hawaiian Electric Companies

Arizona Public Service

Salt River Project

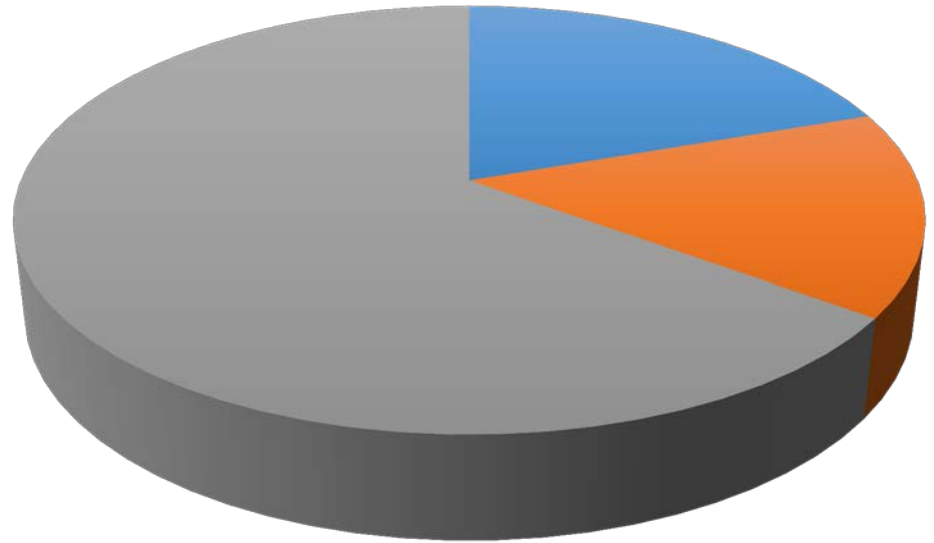
# No “one-size-fits-all” approach

- Differing objectives
  - Regulatory environments
  - Local distribution system considerations
- It appears U.S. utilities will not retrofit inverters (unlike parts of Europe)

# Pacific Gas & Electric

Most solar capacity of any U.S. utility – 5,386 MW  
35% of solar portfolio is distributed  
1,038 Watts per customer

- 1,058 MW residential
- 832 MW non-residential



# California's Rule 21 drives the roll out

California Energy Commission and Public Utilities Commission revised interconnection requirements

Smart Inverter Working Group convened to inform implementation

Roll out in 3 phases

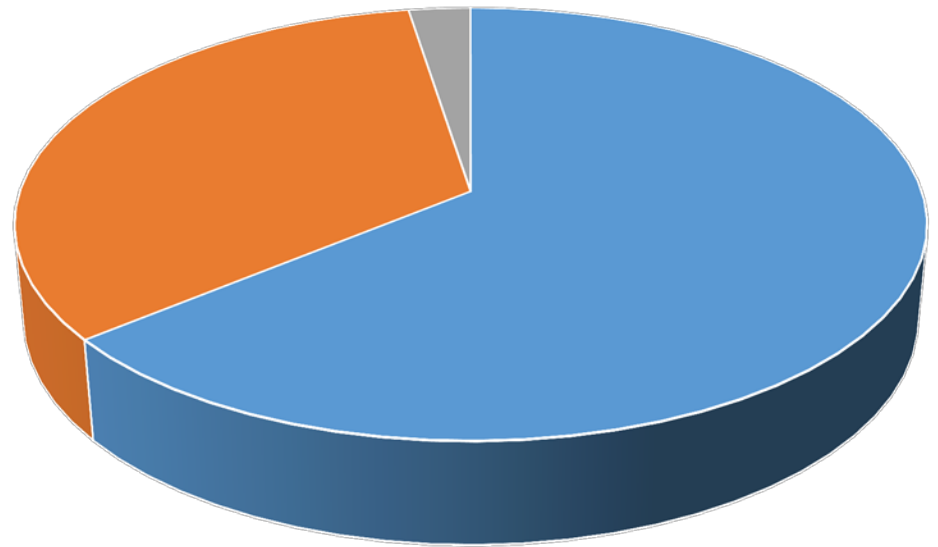
1. Autonomous functionality
2. Communications capabilities and cybersecurity
3. More advanced functionality, but still in development

# Hawaiian Electric Companies

97% of solar capacity is customer sited  
over 13% of all customer accounts have PV  
60,578 interconnections

473 MW of solar capacity  
1,042 Watts per customer

- 303 MW residential
- 158 MW non-residential



# Massive customer adoption drives roll out

Island grids make inverter response to voltage and frequency even more important than for other utilities

Wider frequency and voltage ride-through settings

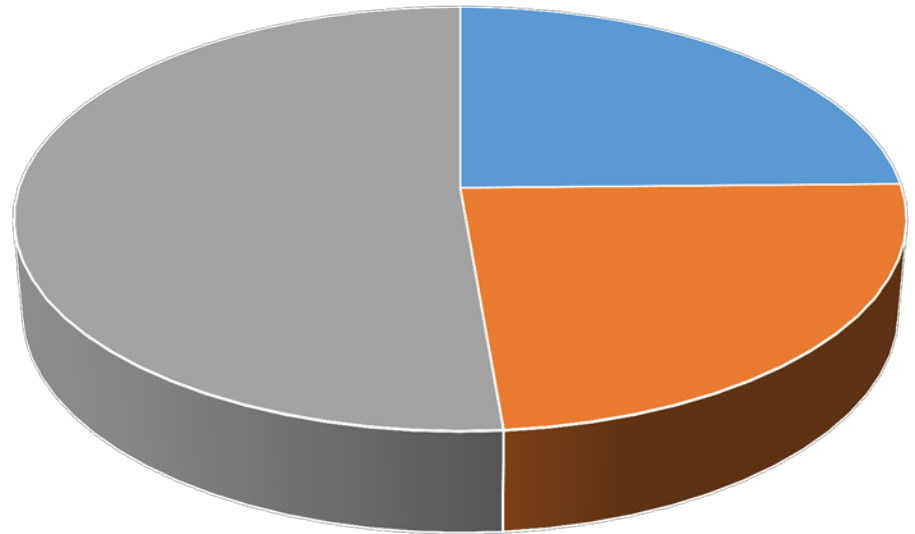
“Must trip by” settings revised to “must ride through unless”

Further voltage support operations under consideration

# Arizona Public Service

935 MW of solar capacity – 4th in the U.S.  
49% of solar portfolio is distributed  
804 Watts per customer

- 231 MW residential
- 224 MW non-residential





# Research and development drives the roll out

Pilot features utility-owned rooftop PV systems

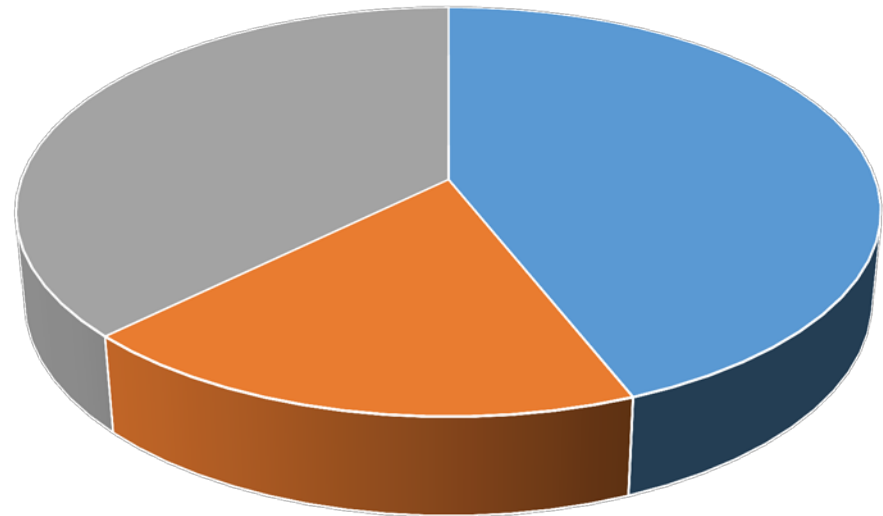
Testing use cases for advanced inverter functionality with comprehensive grid modernization strategies

Robust communications capabilities integrate inverters with distribution control center

# Salt River Project

225 MW of installed solar capacity  
63% of solar portfolio is distributed  
224 Watts per customer

- 99 MW residential
- 42 MW non-residential



# Utility-owned inverters drive the roll out

1,000 inverters testing three operating profiles

- 600 autonomous inverters with enhanced set points
- 200-300 inverters using seasonal profiles
- 100 fully-enabled inverters with robust communications connectivity

# Utility-owned inverters drive the roll out

SRP will own the inverters for the duration of the pilot

Pilot distribution management system

Robust communications testing and integration with existing distribution operations

# Key Findings

1. Equipment standards have not kept pace with technology
2. Autonomous functions can be readily deployed at low cost
3. Communications-based functionality is a tradeoff between inverter capabilities and implementation cost
4. Inverter retrofits can be effectively managed

# Ryan Edge

Research Analyst

202-559-2031

[redge@solarelectricpower.org](mailto:redge@solarelectricpower.org)



Smart Electric  
Power Alliance

# Advanced Inverter Regulation and Standards Update

Emergent Considerations for  
Advanced Inverter Deployment

NREL Webinar, 28 April, 2016

John Berdner

Senior Director of Regulatory and Policy Strategy

# Presentation Outline

- Overview of US Codes, Standards and Regulatory Structure
- Regulatory Linkages
- Review of Current Standards Development Activities
- State Interconnection Rules Update
- Summary and Conclusions



# US Codes / Standards / Regulatory Structure

NEC Article 690.4(B) requires equipment to be Listed for PV applications

UL 1741 is an equipment certification Standard and references IEEE 1547.1 tests

IEEE 1547.1 is the equipment compliance testing Standard for IEEE 1547

IEEE 1547 is the interconnection requirements Standard

Energy Act of 2005 Mandates use of IEEE 1547 as the National Standard

# Energy Act of 2005 (excerpt)

- SEC. 1254. INTERCONNECTION.
- (a) ADOPTION OF STANDARDS.—Section 111(d) of the Public Utility Regulatory Policies Act of 1978 (16 U.S.C. 2621(d)) is amended by adding at the end the following:

“(15) INTERCONNECTION.—Each electric utility shall make available, upon request, interconnection service to any electric consumer that the electric utility serves. For purposes of this paragraph, the term ‘interconnection service’ means service to an electric consumer under which an on-site generating facility on the consumer’s premises shall be connected to the local distribution facilities. ***Interconnection services shall be offered based upon the standards developed by the Institute of Electrical and Electronics Engineers: IEEE Standard 1547 for Interconnecting Distributed Resources with Electric Power Systems, as they may be amended from time to time.*** In addition, agreements and procedures shall be established whereby the services are offered shall promote current best practices of interconnection for distributed generation, ***including but not limited to practices stipulated in model codes adopted by associations of state regulatory agencies. All such agreements and procedures shall be just and reasonable, and not unduly discriminatory or preferential.***”.

# Linkages (1)

- **Federal Energy Act of 2005 Section 1254 – Excerpt 1**
  - Interconnection services **shall be offered based upon the standards developed by the Institute of Electrical and Electronics Engineers: IEEE Standard 1547** for Interconnecting Distributed Resources with Electric Power Systems, as they may be amended from time to time.
- **IEEE 1547**
  - **1.1 Scope** This standard **establishes criteria and requirements for interconnection of distributed resources (DR) with electric power systems (EPS).**
  - **1.2 Purpose** This standard provides **a uniform standard for interconnection of distributed resources with electric power systems.** It provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection. The requirements shall be met at the point of common coupling (PCC), although the devices used to meet these requirements can be located elsewhere. This standard applies to interconnection based on the aggregate rating of all the DR units that are within the Local EPS. The functions of the interconnection system hardware and software that affect the Area EPS are required to meet this standard regardless of their location on the EPS. **The stated specifications and requirements, both technical and testing, are universally needed for interconnection of DR, including synchronous machines, induction machines, or power inverters/converters,** and will be sufficient for most installations.



# Linkages (2)

- **IEEE 1547.1**

- **1.1 Scope** This standard specifies the type, production, and commissioning tests that **shall be performed to demonstrate that the interconnection functions and equipment of the distributed resources (DR) conform to IEEE Std 1547.**
- **1.2 Purpose** Interconnection equipment that connects DR to an electric power system (EPS) must meet the requirements specified in IEEE Std 1547. **Standardized test procedures are necessary to establish and verify compliance with those requirements.** These test procedures must provide both repeatable results, independent of test location, and flexibility to accommodate the variety of DR technologies.

- **UL 1741**

- **40.1** A utility-interactive inverter or interconnection system equipment (ISE) **shall comply with the Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE 1547, and the Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547.1,** excluding the requirements for Interconnection Installation Evaluation, Commissioning Tests, and Periodic Interconnection Tests.

# Linkages (3)

- **NFPA 70 (NEC) Article 690.4(B) Equipment.**
  - *Inverters, motor generators, PV modules, PV panels, ac PV modules, dc combiners, dc-to-dc converters, and charge controllers intended for use in PV power systems **shall be listed for the PV application.***
- **State, local or regional interconnection requirements**
  - Examples: CA Rule 21, HI Rule 14H
- **Federal Energy Act of 2005, Section 1254 – Excerpt 2**
  - In addition, agreements and procedures shall be established whereby the services are offered **shall promote current best practices of interconnection for distributed generation, including but not limited to practices stipulated in model codes adopted by associations of state regulatory agencies. All such agreements and procedures shall be just and reasonable, and not unduly discriminatory or preferential.**

# Summary

- **We are in the midst of a historic transition from low penetration DER to high penetration DER**
  - Hawaii – 100% RPS by 2045
  - CA – 50% renewable by 2050
- **Standards development lags market needs in a few key markets**
  - Publication of UL 1741 Supplement A is eminent
  - 1741 SA will act as a bridge until 1547 and 1547.1 full revisions are complete in mid 2017
  - 1741 will be revised again once 1547.1 is published
- **Regulatory structures are also undergoing major change**
  - Mandatory requirements for advanced inverter functionality
  - Mandatory requirements for communications and/or remote update capability
- **Compensation issues for “revenue impacting” functions remain an issue**
  - Where is the line between being a good citizen of the grid and being compensated for ancillary services
  - New business models may be needed to resolve compensation issues.

# IEEE 1547 - History

1547™-2003

## 1547™

**IEEE Standard for Interconnecting  
Distributed Resources with Electric  
Power Systems**

Standards Coordinating Committee 21

Sponsored by the  
Standards Coordinating Committee 21 on  
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage



Published by  
The Institute of Electrical and Electronics Engineers, Inc.  
5 Park Avenue, New York, NY 10016-5967, USA

28 July 2003

Print: SH95144  
PDF: S995144

- **First issued in July 2003**
  - Open for full revision now with likely publication date on or before EOY 2016
- **IEEE 1547.a amendment published in May 2014**
  - Permitted DER to participate in Voltage Regulation
  - Widened trip settings.
  - Allowed other settings by mutual agreement
- **1547.1 is the testing Standard for 1547 which was published in June 2005 (23 months after 1547)**
- **Open for full revision with likely publication date on or before EOY 2017**
- **1547.1a amendment published in March 2015**
  - Test protocols to match new functionality described in 1547.a



# IEEE 1547 - Update

1547™-2003

## 1547™

**IEEE Standard for Interconnecting  
Distributed Resources with Electric  
Power Systems**

Standards Coordinating Committee 21

Sponsored by the  
Standards Coordinating Committee 21 on  
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage



Published by  
The Institute of Electrical and Electronics Engineers, Inc.  
5 Park Avenue, New York, NY 10016-5967, USA

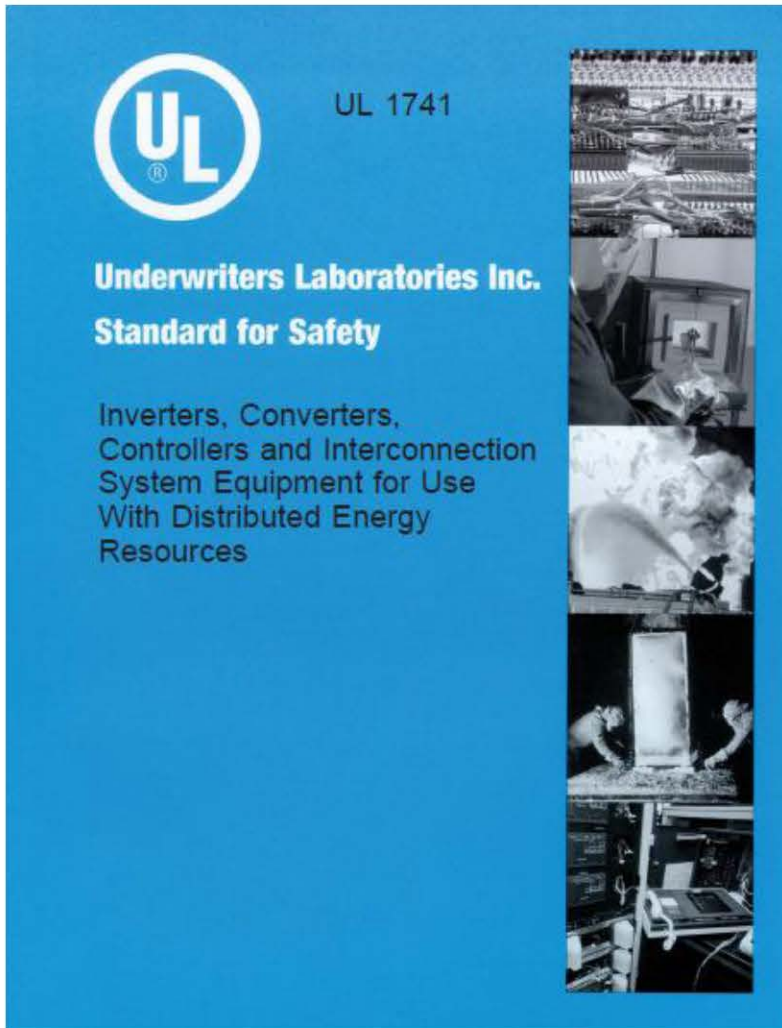
28 July 2003

Print: SH95144  
PDF: SH95144

- **1547 Full revision in development**
  - Target first ballot date EOY 2016
  - Multiple Sub groups active most with weekly conference calls
  - Quarterly full working group meetings
  - Scope:
    - V, f ride through, f/W, Dynamic reactive current support
    - Active and reactive power control (voltage regulation)
    - Advanced anti-islanding
    - Communications
    - Modeling
- **1547.1 full revision**
  - Will occur somewhat in parallel with 1547
  - Working groups recently formed
  - May be able to leverage work done in UL 1741 Supplement A
  - Target first ballot date 1H2017



# UL 1741 / Supplement A - Update



- **Second edition published in January 2010.**
  - Includes references to IEEE 1547.1 for testing
  - Governed by ANSI process for Standards development
- **UL 1741 Supplement A Draft published June 2015**
  - > 400 Comments resolved (per ANSI process)
  - Will likely go to ballot in next 30 days with a 45 day balloting period
  - Likely publication date July 2016
  - Possible delays if re-balloting needed
- **Adoption period will by STP UL likely 12 months or more**
  - Scope of revisions (very large)
  - Bandwidth limitations at NRTL's since all equipment must be recertified

# "Normal" Regulatory Relationship

## IEEE 1547

- IEEE 1547 is the base document which specifies capabilities and behaviors of DER
- IEEE 1547.1 is the test Standard which specifies compliance testing requirements to meet IEEE 1547

## UL 1741

- UL 1741 is the certification Standard which defines product testing requirements based on IEEE 1547.1 and other requirements
- UL 1741 / UL62109 also specify DER construction requirements

## Rule 21

- Rule 21 directly references IEEE 1547 and UL 1741
- Rule 21 specifies default parameter settings for use in CA. Utilities can then specify parameters to meet local requirements

# Rule 21 Regulatory Relationship

## Rule 21

- The SIWG develops a set of technical recommendations
- Rule 21 is created by the CPUC which sets interconnection requirements directly, The majority of those involved have little Standards Development experience.

## UL 1741

- UL 1741 is tasked to develop a set of Supplementary testing requirement used to certify compliance with Rule 21.
- UL 7141 is used as a proxy to IEEE 1547 and 1547.1 in order to speed the adoption of Rule 21 DER (Smart Inverters)

## IEEE 1547

- IEEE 1547.a is developed on an emergency basis to allow reactive power and other setting by mutual agreements
- Full revision of 1547 is now underway. Once 1547 is revised 1547.1 revision can begin. UL 1741 will be harmonized to 1547.1



# State Interconnection Rules - Update

- **CA Rule 21**

- Phase 1 recommendations now in effect via tariffs filed by all 3 IOU's
  - Allowed now, Mandatory 12 months after publication of UL 1741
- Phase 2 Requirements will be via utility interconnection handbook
  - SCE leading effort, first draft available, second draft under development
  - IEC 61850 Data model, SEP 2.0/ IEEE 2030.5 protocol
- Phase 3 recommendations did not achieve broad consensus
  - Unlikely to be incorporated into Rule 21 the near term
  - Compensation issues were major hurdle >> DRP, IDER dockets now underway

- **HI Rule 14H**

- DER Phase 1 mandatory requirements in place as of 1 Jan 2016
  - Ride through, Fixed PF, Ramp Rate control
  - Remote update capability
  - NEM replaced by Grid Supply and Self Supply agreements
- DER Phase 2 will begin soon
  - V/Var, V/W, f/W
  - Compensation issues



# Questions?



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**John Berdner**  
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**Kristen Ardani**  
Solar Analyst (DGIC Moderator)  
NREL

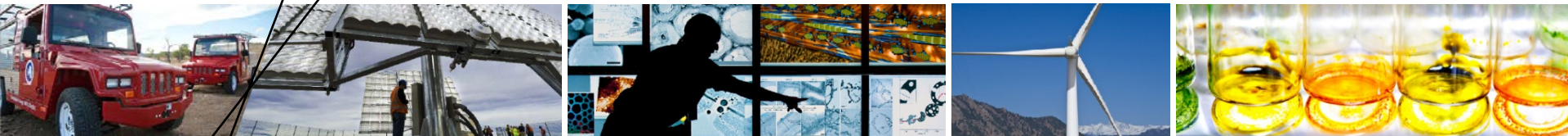
# DGIC and Technical Assistance Resources

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- **Participate in the Collaborative and shape the discussion by signing up through the DGIC web page, below:**

**[http://www.nrel.gov/tech\\_deployment/dgic.html](http://www.nrel.gov/tech_deployment/dgic.html)**

# Thank You!



Kristen Ardani  
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